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FORTRAN PROGRAM FOR SOUND SCATTERING BY LAYERED ISOTROPIC CYLINDER

By

J H James

Summary

Skelton's original Fortran program for predicting time-harmonic sound radiation from an infinite cylinder comprising elastic, viscous and acoustic layers has point forces and monopoles as excitations. It has been extended to cover the case of excitation by a plane wave at arbitrary incidence, and the output may be used for transient radiation/scattering studies. Numerical examples are given, but a computer listing is not included.

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1. INTRODUCTION

Theoretical aspects of acoustic scattering from infinite cylindrical geometry, insonified at an oblique angle, have been given by Flax et al [1] for the case of a solid elastic cylinder and James [2] for the case of a fluid filled cylindrical shell. Skelton [3] has given the theory necessary to calculate sound radiation from a layered cylinder excited by time-harmonic mechanical forces or acoustic monopoles, the layers being composed of acoustic fluids, viscous fluids and elastic solids. Skelton's analysis and computer program have since been modified to cover the important case of sound scattering due to plane wave excitation at oblique incidence, and this substantially forms the content of this report. Theoretical aspects are not discussed as they can be found in the references cited.

2. NUMERICAL EXAMPLES

2.1. General

Figure 1 shows a cylindrically layered system comprising isotropic elastic solids, viscous fluid layers and acoustic fluid layers; governed by the exact linear equations of elastodynamics, viscodynamics and acoustics. The time-harmonic excitations are: mechanical force at elastic layer interface; acoustic monopole in exterior fluid; acoustic monopole in interior fluid; acoustic monopole in acoustic layer; and acoustic plane wave incident at an oblique angle.

The scope of the Fortran program, which calculates far-field acoustics, is evident from its specification which can be found in the Appendix.

2.2. Time-Harmonic MF Scattering

In order to demonstrate the capability of the program, consider a sandwich construction comprising facings of concentric steel cylinders, and a much softer filler material. The SI constraints of the 3 layers, Lamé material properties λ and μ being in GN/m^2, are taken as:

Material	λ	μ	ρ	η	a	b
Top Facing	104.4	75.6	7700	0.01	0.99	1.00
Soft Filler	0.04	0.01	900	0.01	0.91	0.99
Bottom Facing	104.4	75.6	7700	0.01	0.90	0.91

The exterior water has sound velocity 1500 m/s and density 1000 kg/m^3, and there is a vacuum inside the inner steel cylinder. ρ is material density, η is the hysteretic loss factor, a is inner radius and b is outer radius. Figure 2 shows monostatic target strengths (see Appendix for definition) of

a cylinder comprising the outer steel facing alone. The frequency range extends to the medium acoustic ka value of 8.4. The features have been analyzed by Veksler [4] and others in terms of the first symmetric Lamb mode (S_0) and the first antisymmetric (A_0) Lamb mode, with the former mode dominating. In a flat plate these modes correspond to the familiar longitudinal and flexural waves. Figure 3 shows corresponding target strengths of the composite cylinder. In the frequency range to 800 Hz, interactions between the facings via the stiffness of the filler are especially evident at normal incidence. Above this frequency, the outer facing becomes more and more decoupled from the inner facing.

2.3. Time Harmonic HF Scattering

Figure 4a shows monostatic target strengths, at normal incidence, of a steel cylinder of outer radius 1 m and thickness 2 cm. The frequency range extends to the high acoustic ka value of 104.7. The dips below 10 kHz and rapid oscillations above this frequency are predominantly due to the Lamb S_0 and A_0 modes respectively, the dips being explained in terms of resonances and the rapid oscillations as due to coincidence lobe radiation. Figure 4b shows the corresponding plot when the thickness of the cylinder is increased to 10 cm. The influence of higher order Lamb and surface wave modes must be present to a certain extent, but physical explanations in the published literature are unclear. Both these plots resemble the corresponding plots obtained for spherical geometries by White [5], but the oscillations herein are much less marked due to weaker resonant behaviour by cylinders.

2.4. Transient Scattering

Time-harmonic excitation has been assumed throughout, but transient excitations are readily available using a recently developed software tool [6] for transient response calculations from time-harmonic spectra. For example, Figure 5a shows the (total) far-field sound level spectrum, at θ=90 and ϕ=0, of the composite cylinder when a time-harmonic monopole is located close to its surface. Figure 5b shows the transient far-field sound pressure when the excitation is a 400 Hz sine wave which is on for a single cycle. The early response (note the time scale is relative) is dominated by direct radiation from the monopole and to a lesser extent by its specular reflection from the cylinder surface. The extended ringing in the tail is of small amplitude.

3. CONCLUSIONS

The numerical results demonstrate that the Fortran program, arising from Skelton's theoretical work extended to cover the case of excitation by a plane wave at oblique incidence, is a useful research tool for analyzing the acoustics of cylinders comprising isotropic layers. Time-harmonic responses are the standard output of the program, but transient responses are readily available using auxiliary software.

4. ACKNOWLEDGEMENT

The not inconsiderable effort of E A Skelton when doing the original theoretical work and computer programming is much appreciated.

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APPENDIX A

Program Specifications of CYL001.FOR

Sound radiation and scattering by infinite layered cylinder, see Figure 1 for geometry, comprising isotropic layers of elastic solid, viscous fluid and acoustic fluid.

Item 01:

N The number of layers.

Item 02: for each layer, in outer to inner order, give the following.

LAM real Lamé first constant.
MU real Lamé second constant.
ELAM hysteretic loss-factor for first Lame constant.
EMU hysteretic loss-factor for second Lame constant.
RHO density.
B outer radius of layer.
A inner radius of layer.

according to the table:

LAM	MU	ELAM	EMU	RHO	
0.0	0.0	η_c	c	ρ	for acoustic layer.
0.0	μ	0.0	c	ρ	for viscous layer.
λ	μ	η_λ	η_μ	ρ	for elastic layer.

in which c is sound velocity; ρ is density; λ and μ are Lamé constants for the elastic layer, and μ is the dynamic coefficient of viscosity for the viscous fluid layer. η_λ, η_μ and η_c are hysteretic loss-factors, viz. $c=c(i-i\eta_c)$, $\lambda=\lambda(1-i\eta_\lambda)$, $\mu=\mu(1-i\eta_\mu)$. Note a fluid loss factor η_c is equivalent to a structural loss factor of $2\eta_c$. If an elastic solid has Young's modulus E and Poisson's ratio υ, then the equivalent Lamé constants are $\lambda=E\upsilon/(1+\upsilon)(1-2\upsilon)$ and $\mu = E/2(1+\upsilon)$.

Item 03:

RHOEXT density exterior acoustic fluid.
CEXT sound velocity.

Item 04:

RHOINT density interior acoustic fluid. Set to 0.0 if vacuum.
CINT sound velocity. Set to 0.0 if vacuum.

Item 05:

ITYPE =0 for point force excitation.
=1 for exterior point source.
=2 for interior source.

=3 for source inside layer.
=4 for plane wave excitation.

Item 06: only if ITYPE=0

NF number of point forces, then for each force:
FCOM amplitude of force; complex number, eg (1.0,0.0).
IFACE interface number of point of application, the outer surface being interface 1, etc.
IRZ = 1/2/3 for force acting in radial/tangential/axial direction.
ZF axial coordinate of force.

Item 06: only if ITYPE = 1,2,3

NS number of point sources, then for each source:
CAMP amplitude of source; complex number, eg (1.0,0.0).
ILA layer number of source location, the outer layer being layer 1, etc. Set to 0 for ITYPE = 1,2.
RS radial coordinate of source.
ZS axial coordinate of source.

Item 07:

THETA elevation angle in degrees of observation point.
PHI circumferential angle in degrees of observation point.

Item 08:

NFREQ number of frequencies.
FMIN start frequency.
FMAX final frequency.

Item 09:

NBES0 terms in Fourier summation at first frequency.
NBES1 terms in Fourier summation at last frequency.

1. For ITYPE = 0,1,2,3 the program output is a table of far-field sound pressure level in dB ref. 1 micropascal at 1 m, assuming (if logic permits the user to do so) that the excitation amplitudes are normalized to rms, ie an excitation of (1.0,0.0) is assumed to be an rms amplitude of unity. The first column of output is the frequency; the second column of output is the far-field sound level; the third column of output is the same as the second column for ITYPE=0,2,3 and for ITYPE=1 it is the far-field pressure assuming a rigid immovable exterior boundary. Excitations for ITYPE=0,1,2,3 are applied at the circumferential angle ϕ=0. The angles θ and ϕ of the far-field observation point are selected in Item 07.

2. For ITYPE=4 the second column of the program output is the target strength of the elastic system and the third column is the target strength of the system assumed rigid and immovable. The incident plane wave for ITYPE=4 comes from the direction ϕ_i=180. The angle of measurement ϕ should be chosen as 180 for monostatic target strength. Several hours of contemplation will reveal that for this substantially two-dimensional scattering problem, the azimuthal angle of incidence θ_i is identical to the

azimuthal angle θ of the observation. The target strength is defined as

$$T = 20.\log_{10}[(r/P_i)^{1/2}|p_{sf}(r,\theta_i,\phi,\phi_i=180)|]$$

where P_i is the amplitude of the incident wave and p_{sf} is the pressure scattered to the far-field.

3. Input is from the file FOR005.DAT and output is to the file FOR006.DAT. Results are also put on disk file in a format suitable for plotting by a system dependent program GRAPH1.

4. Maximum values, which can be changed by altering the Fortran PARAMETER statement are: NLAY=10, NFREQ=501, NF=10, NS=10, NBES1=100

5. Field quantities of interest are expanded as Fourier series in the circumferential coordinate ϕ. Initially, run the job with five frequencies and select and change NBES0 and NBES1 until the answers appear to have converged to a sufficient accuracy. Start with NBES0=5 and NBES1=5+ka, say. Note Bessel functions in the Fourier series may cause overflow if NBES0 or NBES1 is too large. Ideally the program should be run in a Fortran environment in which 64 bit arithmetic with a large exponent is used.

6. Fatal error numbers in output:

10 = error when calculating system inverse in LAYER.
11 = error when calculating layer matrix inverse in SCALC.

7. An auxiliary Fortran program CYL002 is available for calculating real wavenumber versus frequency plots for selected circumferential harmonics. These dispersion plots help in the physical interpretation of radiation/scattering spectra.

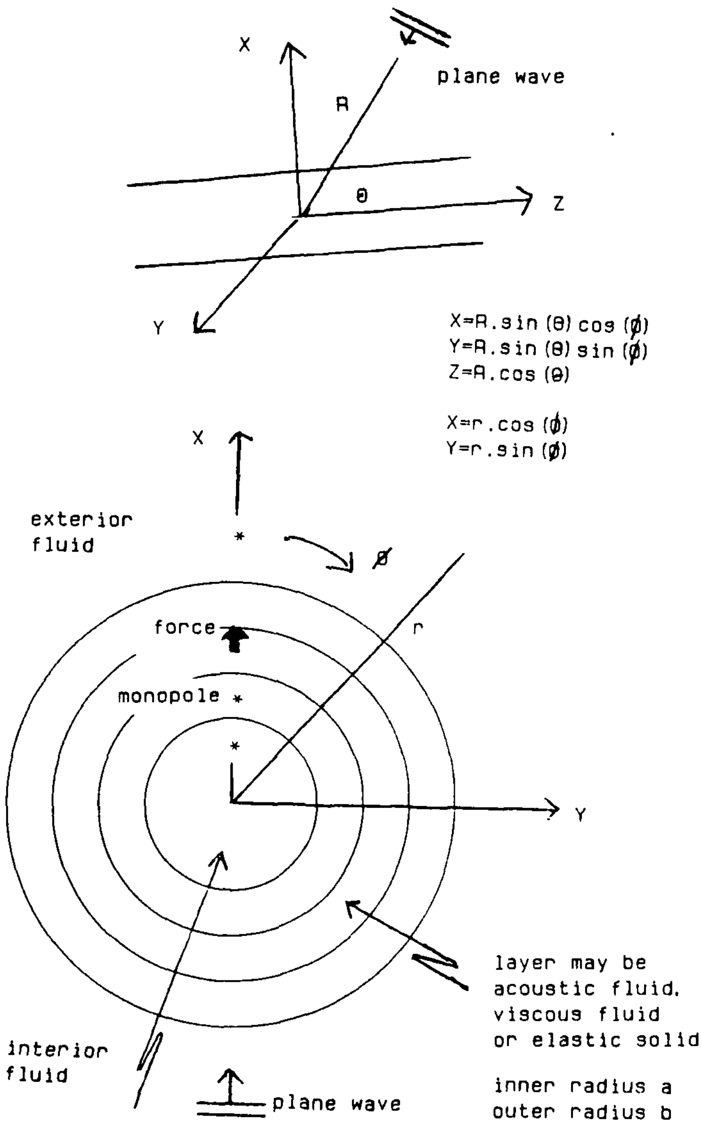

Fig.1 Layered System and Excitations

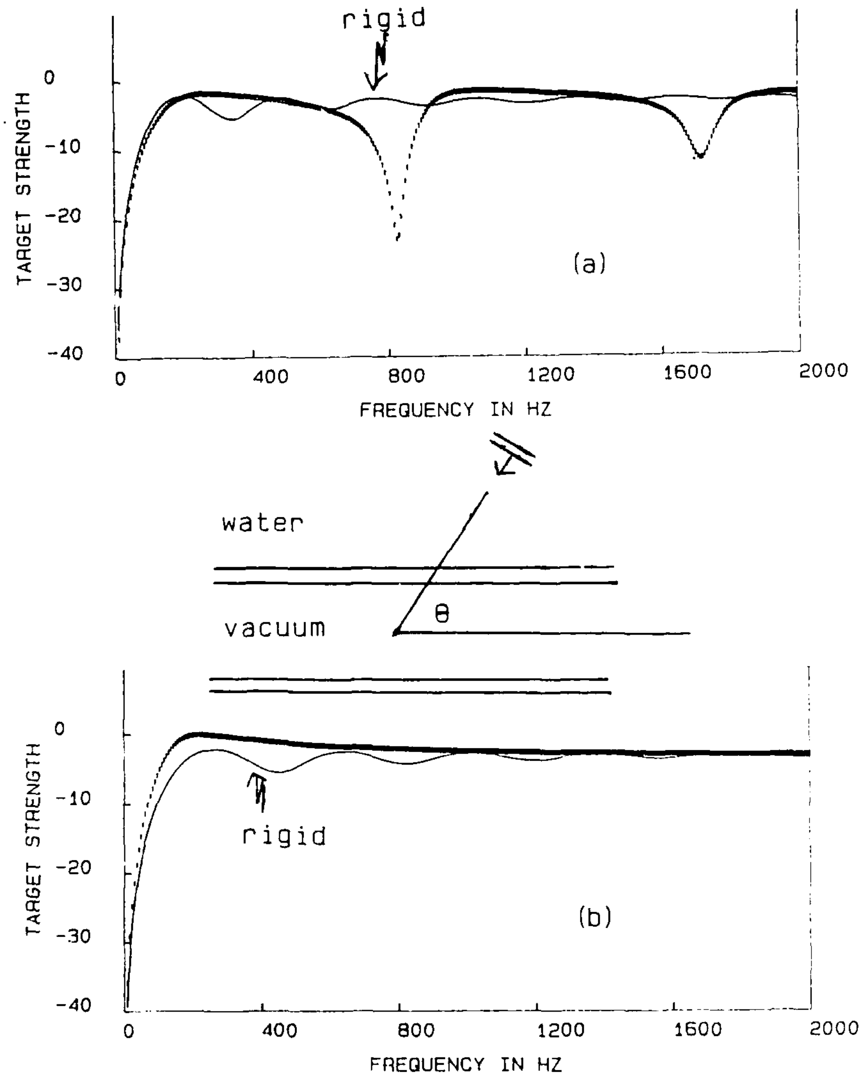

FIG.2 Monostatic target strength of thin steel cylinder. (a) θ=90 (b) θ=50.

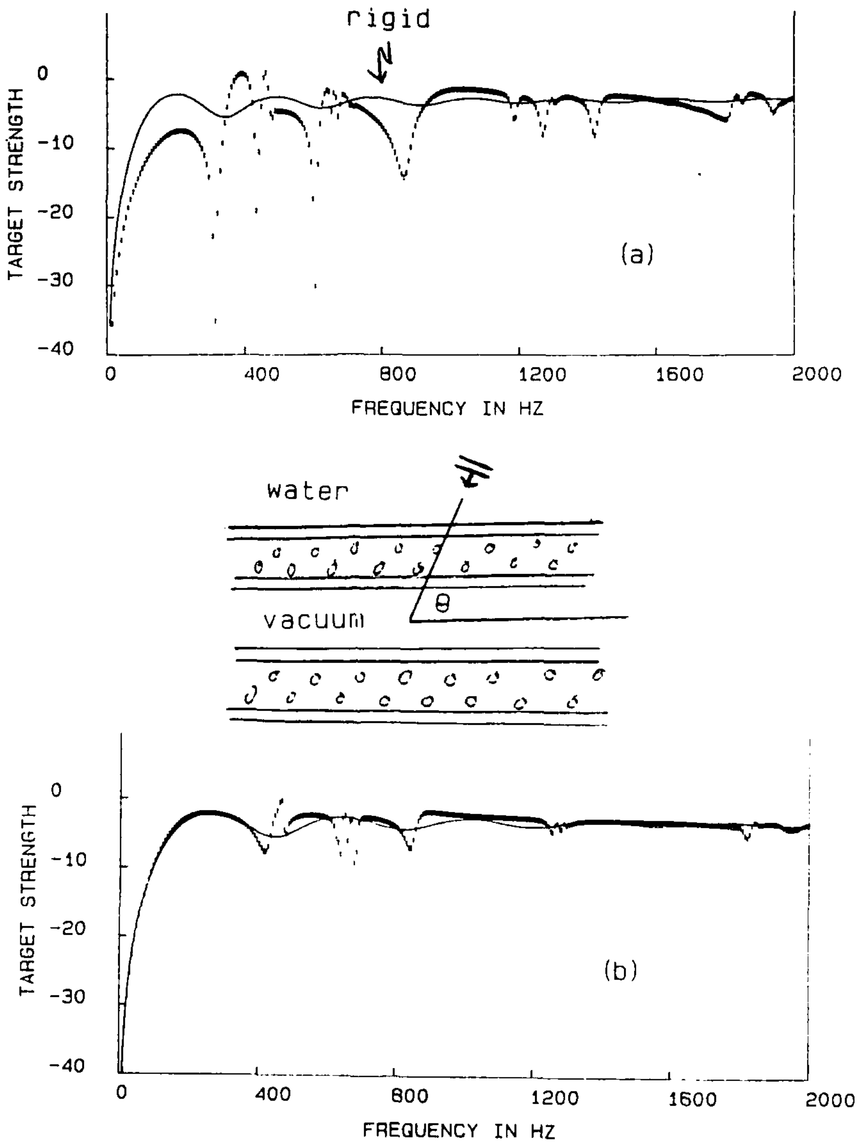

FIG.3 Monostatic target strength of composite cylinder. (a) θ=90 (b) θ=50.

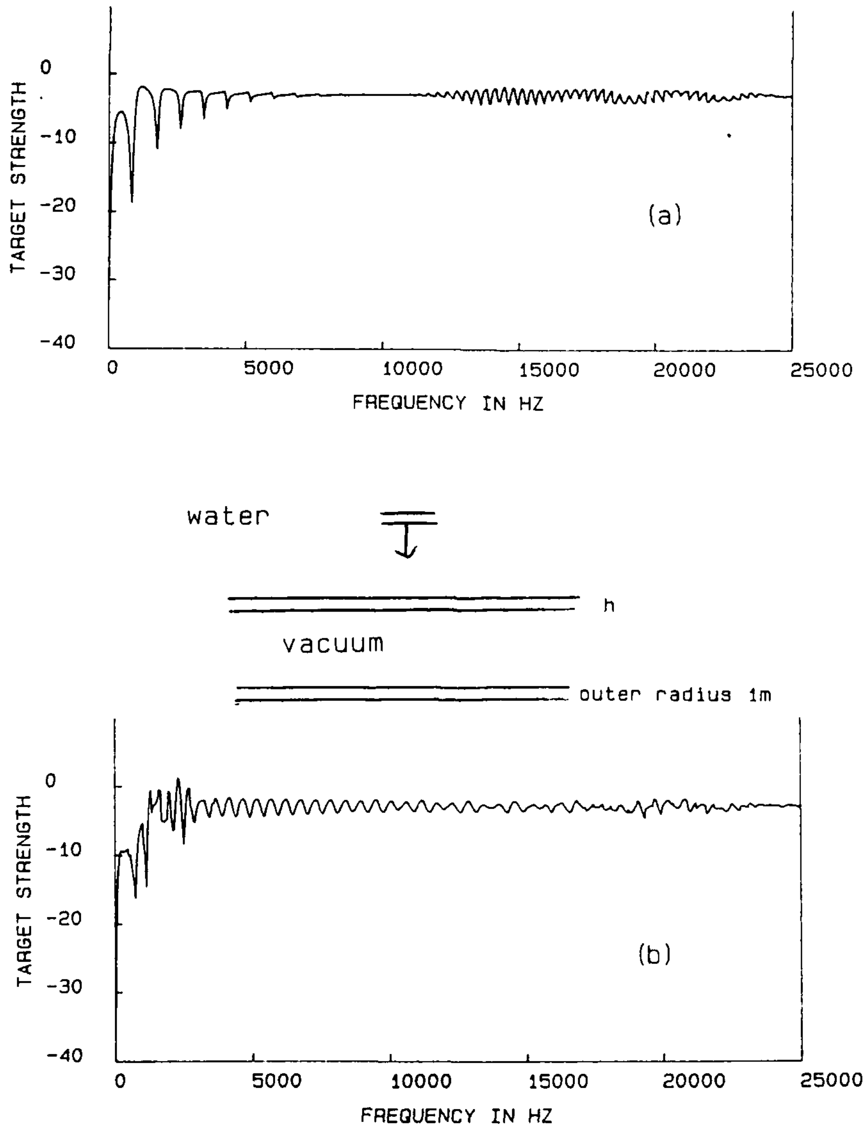

FIG.4 High frequency monostatic target strength of steel cylinder. (a) h=2cm (b) h=10cm.

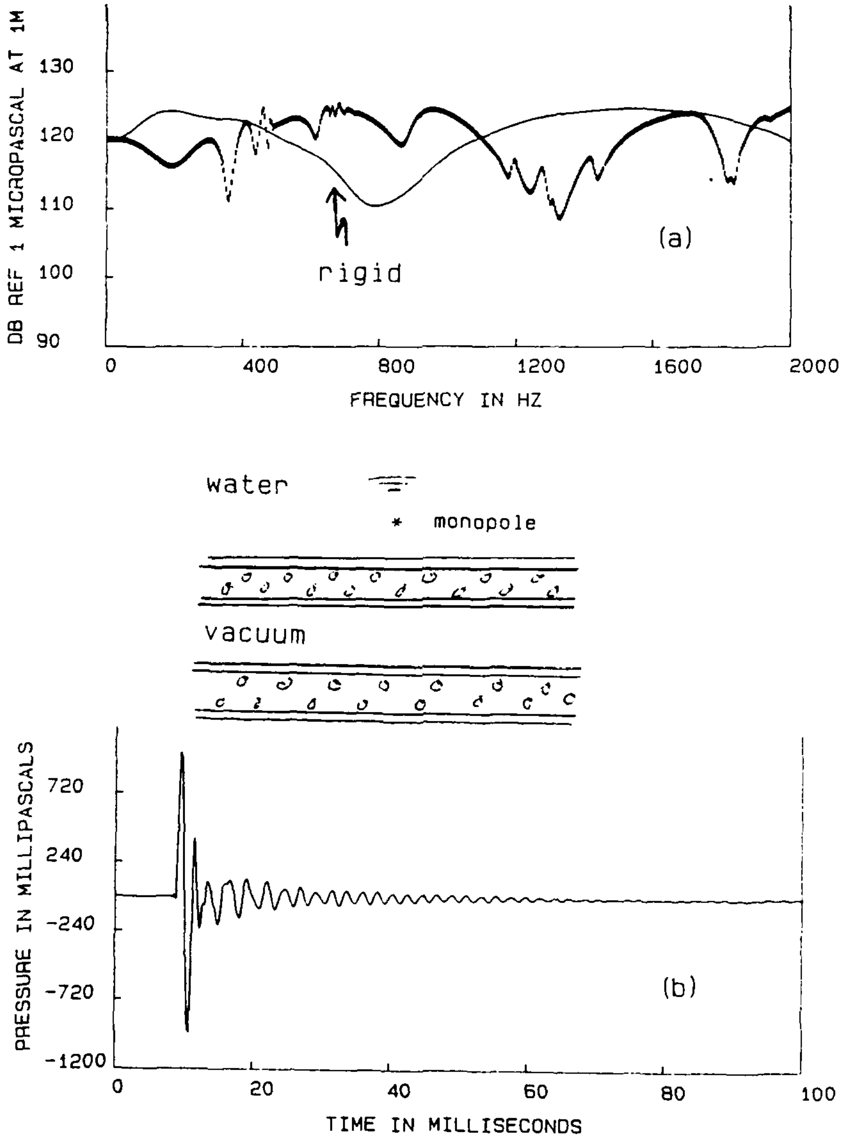

FIG.5 Far-field radiation from source close to composite cylinder. (a) time-harmonic spectrum (b) transient response.

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